ASSESSMENT OF DISTURBANCE IMPACT OF HYDRAULIC JACK IN PILE PENETRATION USING ARTIFICIAL TRANSPARENT CLAY

NABEEL KATFAN LWTI

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Geotechnics)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JUNE 2015

To my beloved family

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious and Most Merciful.

Alhamdulillah, praise be to Allah for his blessing and giving me strength to complete this project. First and foremost, my deepest gratitude goes to the Ministry of Higher Education and scientific Research in Iraq for awarding me the scholarship and the opportunity to continue my study in Universiti Teknologi Malaysia (UTM).

My appreciation to my supervisor, Dr. Ahmad Safuan A. Rashid for his constant academic guidance, patience and all the precious time spent in the preparation of this project. Without his guidance, this project will not have been accomplished. I am also very thankful to all the staffs in Geotechnical Laboratory, UTM for their assistance and encouragement.

My warmest appreciation also extends to all my friends for helping me directly or indirectly in completing this project. Finally, my deepest appreciation goes to my beloved family that give me undivided supports and comforts during this challenging period. For every one of you, thank you very much.

ABSTRACT

Different types of pile foundation are widely used in geotechnical engineering with different methods of installation. Thus, ground vibration due to impact of driving of the preformed pile in a soft compressible soil causes the lateral displacement of soil and foundations of nearby structures. The pile jacking method offers an alternative technique of pile installation, which allows pre-formed piles to be installed with minimal noise and vibration. This study used small-scale physical modeling method to investigate the movement during pile installation into the soil. The model was prepared by using a mixture of amorphous silica and mineral oil which, was subsequently consolidated in a transparent chamber. The pile model was driven vertically at the center of the model at a different vertical speed. The patterns of displacement distribution were obtained using particle image velocimetry technique. This result can be used to assess the disturbance Impact due to pile installation on underground services and archaeological remains underneath the ground surface.

ABSTRAK

Pelbagai jenis asas cerucuk telah digunakan dengan meluas dalam kejuruteraan geoteknik dengan pelbagai kaedah pemasangan. Oleh itu, getaran tanah yang disebabkan oleh kesan dari cerucuk siap bentuk yang ditanam ke dalam tanah lembut yang boleh mampat menyebabkan anjakan mendatar tanah dan struktur asas yang berdekatan. Kaedah pemasangan cerucuk tusukan menawarkan satu teknik alternatif pemasangan cerucuk yang membolehkan cerucuk pra-bentuk dipasang dengan bunyi bising dan getaran yang minimum. Kajian ini telah menggunakan kaedah pemodelan fizikal berskala kecil untuk mengkaji pergerakan semasa pemasangan cerucuk ke dalam tanah. Model tersebut telah disediakan menggunakan satu campuran silika amorfus dan minyak mineral yang kemudiannya disatukan di dalam sebuah turus lutsinar. Model cerucuk telah ditanam secara menegak di pusat model pada satu kelajuan tegak yang berbeza. Corak pengagihan sesaran diperolehi menggunakan teknik velosimetri imej zarah. Keputusan ini boleh digunakan untuk menilai kesan gangguan yang disebabkan oleh pemasangan cerucuk bawah tanah dan kesan kepada jasad arkeologi yang terdapat di bawah permukaan tanah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Material
BS	-	British Standard
SPM	-	Strain Path Method
SSPM	-	Shallow Strain Path Method
CEM	-	Cavity Expansion Method
BS	-	Active Measurement Project
PIV	-	Particle Image Velocimetry
RI	-	Reflective index
VST	-	Vane shear test

LIST OF SYMBOLS

v	-	Drive vertical speed
V	-	Dimensionless velocity
C_u	-	Undrained shear strength
C_v	-	Coefficient of consolidation
C_c	-	Compression index
C_s	-	Swelling index
D	-	Diameter
H	-	Height
k	-	Hydraulic conductivity
m_v	-	Coefficient of compressibility
e	-	Void ratio
R	-	Radius

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Driven pile is the most widely used as foundation methods in ground with serious and difficult conditions. It supports road embankment, bridge approach abutment, industrial building. It is also used in high rise buildings which spans several meters above and below the ground level for storage and parking of vehicles. Dynamic pile installation method has been associated with the soil displacement around and beneath it with subsequent deformation of the soil. The pile driving induced soil movement which poses a serious geotechnical hazard and a potential damage to the adjacent facilities (Ceser and Andrew, 2001). Thus, ground vibration due to impact of driving of the preformed pile in a soft and compressible earth material will cause the lateral displacement of soil and foundations of nearby structures (Massarsch and Wersall, 2013). Furthermore, conventional pile installation method is accompanied with noise (White, 2002). Thus, constituting an ill-suited source of disturbance to the urban environment (Shepley and Bolton, 2013). Also, there were many efforts to predict the settlement of both single and pile groups under working load (Qian-Qing, 2010; Zhongjin *et al*, 2012; Chun, 2013).

Several other researchers have been conducted on the influence of pile installation method on soil, and generated vibration within the vicinity. And the method could either be vibratory pile driving, impact pile driving and jacking. Impact pile driving is the oldest known driving technique which produces transient vibration in the ground. During the process a ram mass is dropped from a specific height and strikes the pile head with impact downward velocity. This provides the driving energy. It generates high energy and vibration levels, though it can be used to install piles in a difficult soil condition. Due to practical, environmental and the economic concern vibratory pile driving technology is preferred to other methods, however it poses a potential dangerous vibration level. Jacking, though, has induced no environmental disturbance, due to their low disruptive nature which generates little noise and few ground vibrations (White *et al.*, 2000). In addition, they often require fewer enabling works due to the smaller machinery (Goh *et al.*, 2004).

Researches by Randolph, (1979); Shepley and Bolton, (2013); Yu-nong and Jing-pei, (2009); Chun *et al.*, (2013) and Ekanyake *et al.*, (2013) have confirmed the influence of pile driving method as a major triggering factor of the ground vibration which causes cracks on the adjacent facilities and other underground structures such as tunnels. This coupled with the noise is more pronounced in urban areas. Hence, Jacking technique is used where sensitive environmental condition is less preferred. Ground vibration during pile installation depends on the driving method: pile depth: interaction between driving machine, the pile and the soil: wave propagation through the soil.

In the cause of pile driving or jacking, a volume of soil equal to that of the pile is being displaced (Roy *et al.*, 1981). When the pile is installed in a saturated cohesive soil, shear forces and pore pressure develop in the soil surrounding the pile. Thus, effective stresse increases due to dissipation of excess pore water pressure over time. Consequently, settlement of a single driven pile in soft clay occurs with time under the working load (Chun, 2013). This settlement due to single driven pile usually more pronounced effect within first four years (Chun, 2013). It decreases gradually until it eventually becomes stable. Another effect is the lateral displacement of the ground at depth with the eventual heave of the ground surface (Massarsch and Wersäll, 2013).

Capacity of pile depends on the shear strength of the soil, which is determined by the rate of loading as confirmed by Casagrande *et al.* (1948);

Whitman (1957); Bjerrum *et al.* (1958) and Crawford, (1959). In the process of pile driving in a soft compressible soil, cohesive earth material is displaced.

Even though, many researchers have been carried out on the various methods of pile installation in a soft compressible soil, pile jacking is a relatively new technology, thus, not much research have been carried out (White and Dicks, 2007). An attempt has been made to study the influence of pile jacking technology by different researchers. White and Diks (2007) have reviewed the mechanisms governing the shaft and base resistance of displacement piles. Due to this displacement and cohesion between the clay and the pile shaft, forces are usually developed in both the soil and the pile and some of this still remained after installing force has been removed. This account for the jacked pile being in compression immediately after installation and in equilibrium with tensile forces in the soil. And therefore, set up several field measurements. Some authors have made efforts to develop model to assess the driving efficiency investigating the bearing capacity of driven piles and the driveability (Smith, 1960; Rausche, 1992 and Holeyman, 2002). And several others focused on the environmental effects as reported (Clough, 1980; Wiss, 1981; and Dowding, 1996).

1.2 Problem Statement

It has been established that pile driving trigger ground vibration irrespective of installation method. Thus, it causes damage such as cracks and uneven settlement to the adjacent facilities. Despite the number of researches conducted by many authors using different methods, none of which is vibration free. And generally pile driving is environmentally unfriendly due to the noise generated in an urban area with a very sensitive condition. Also, settlement of pile under working load is undesirable.

1.3 Objectives

The aim of this study is to assess the movement of soil around the pile foundation during installation and its associated impacts of damage to existing underground structures. It can be achieved through the following objectives:

1. To develop a small-scale physical modeling method, to observe the deformation field within the soil body during the pile penetration using an artificial transparent soil.

2. To quantify the soil movement during the pile installation by using physical model test.

3. To establish the impact of disturbance due to the pile installation under different penetration rate.

1.4 Scope and Limitation

The study will consider the ground deformation using hydraulic pile jacking system in a soft compressible clay. One dimensional consolidation test was conducted to assess the soil property due to soil pile interaction in an artificial transparent soil.

1.5 Significance of Study

The displacement pile installation methods jacking or dynamic driving has an effect on the deformation of the soil during installation, and the resulting stress field around the pile. These factors affect the pile behavior during subsequent loading. In design practice, the effect of installation method is rarely considered when assessing the response of a pile foundation. The hydraulic jack in piling system is simple and fast, so the operating costs can be minimal. This system is suitable for implementation in urban areas, environmentally sensitive sites, and close to sensitive structures.

REFERENCES

Adrian, R. J. (1991). Particle-imaging techniques for experimental fluid mechanics. *Annual review of fluid mechanics*, 23(1), 261-304.

Atkinson, J. (1993). *An introduction to the mechanics of soils and foundations: through critical state soil mechanics*. McGraw-Hill Book Company (UK) Ltd.

Baligh, M. M. (1985). Strain path method. *Journal of Geotechnical Engineering*, 111(9), 1108-1136.

Basu, P., Prezzi, M., Salgado, R., & Chakraborty, T. (2013). Shaft resistance and setup factors for piles jacked in clay. *Journal of Geotechnical and Geoenvironmental Engineering*,140 (3).

Bjerrum, L., Simons, N., & Torblaa, I. (1958). *The effect of time on the shear strength of a soft marine clay*. In Proc. Conf. On Earth Pressure Problems. Bruxelles. I.

Cooke, R. W., & Price, G. (1973). *Strains and displacements around friction piles*. Building Research Establishment, Department of the Environment.

Cooke, R. W., Price, G., & Tarr, K. (1979). Jacked piles in London Clay: a study of load transfer and settlement under working conditions. *Geotechnique*, 29(2), 113-147.

Gill, D. R. (1999). *Experimental and theoretical investigations of pile and penetrometer installation in clay*. Doctoral dissertation, PhD Thesis, Univ. of Dublin (Trinity College), Ireland.

Gue, S. S. (1984). *Ground heave around driven piles in clay*. Doctoral dissertation, University of Oxford.

Hagerty, D. J. (1969). *Some heave phenomena associated with pile driving*. Doctoral dissertation, University of Illinois at Urbana-Champaign).

Head, K.H., (2011). *Manual of Soil Laboratory Testing*, Vol.2 Permeability, Shear strength and Compressibility Tests, 3rd edition, Whittles Publishing.

http://www.jackinpile.com.my

http://www.osp.mans.edu.eg/deepfoundation

Iskander, M. (2010). *Modelling with transparent soils*: Visualizing soil structure interaction and multi phase flow, non-intrusively. Springer Science & Business Media.

Iskander, M. G., Lai, J., Oswald, C. J., & Mannheimer, R. J. (1994). *Development of a transparent material to model the geotechnical properties of soils. development*, 17(4).

Iskander, M. G., Liu, J., & Sadek, S. (2002). Transparent amorphous silica to model clay. *Journal of Geotechnical and Geoenvironmental Engineering*, 128(3), 262-273.

Jaeger, R. A., DeJong, J. T., Boulanger, R. W., Low, H. E., & Randolph, M. F. (2010). *Variable penetration rate CPT in an intermediate soil*. In Proceedings of the 2nd International Symposium on Cone Penetration Testing (CPT'10), Huntington Beach, Calif. Edited by Mitchell et al.

Kim, K., Prezzi, M., Salgado, R., & Lee, W. (2008). Effect of penetration rate on cone penetration resistance in saturated clayey soils. *Journal of Geotechnical and Geoenvironmental Engineering*, 134(8), 1142-1153.

Kim, K., Prezzi, M., Salgado, R., & Lee, W. (2010). *Penetration rate effects on cone resistance measured in a calibration chamber*. In 2nd International Symposium on Cone Penetration Testing.

Lehane, B. M., & Gill, D. R. (2004). Displacement fields induced by penetrometer installation in an artificial soil. *International Journal of Physical Modelling in Geotechnics*, 4(1), 25-36.

Liu, J., Iskander, M. G., & Sadek, S. (2003). Consolidation and permeability of transparent amorphous silica. *Geotechnical Testing Journal*, 26(4), 390-401.

Luo, Z. Y., Zhu, X. R., & Wang, L. F. (2006). *Field studies on effect of jacked pile on adjacent buildings and roads in clay.* In Foundation Analysis and Design@ sInnovative Methods (pp. 195-202). ASCE.

Mahajan, S. P., & Budhu, M. (2006). Viscous effects on penetrating shafts in clays. *Acta Geotechnica*, 1(3), 157-165.

Massarsch, K. R., & Wersäll, C. (2013). *Cumulative Lateral Soil Displacement due to Pile Driving in Soft Clay.* Sound Geotechnical Research to Practice, Geotechnical Special Publication Honoring Robert D. Holtz, ASCE, Reston, Virginia.

Murthy, V.N.S, (2002). *Geotechnical Engineering:Principles and Practices of Soil Mecahnics and Foundation Engineering*, CRC Press, Prism Books Pvt. Ltd, India.

NI, Q., Hird, C. C., & Guymer, I. (2009). Physical modelling of pile penetration in clay using transparent soil and particle image velocimetry. *Geotechnique*, 60(2), 121-132.

Randolph, M. F., Carter, J. P. & Wroth, C. P. (1979). *Geotechnique* 29, No. 4, 361-393.

Sadek, S., Iskander, M. G., & Liu, J. (2002). Geotechnical properties of transparent silica. *Canadian Geotechnical Journal*, 39(1), 111-124.

Sagaseta, C., & Whittle, A. J. (2001). Prediction of ground movements due to pile driving in clay. *Journal of Geotechnical and Geoenvironmental Engineering*, 127(1), 55-66.

Sagaseta, C., Whittle, A. J., & Santagata, M. (1997). Deformation analysis of shallow penetration in clay. *International Journal for Numerical and Analytical Methods in Geomechanics*, 21(10), 687-719.

Salih, A. G. (2013). Transparent Soil as a Substitute for Natural Soils in Geotechnical Modeling. *Electronic Journal of Geotechnical Engineering*, 18, 1057-1065.

Stanier, S. (2011). *Modelling the behavior of Helical Screw piles,* PhD thesis, University of Sheffield.

Terzaghi, K., Peck, R.B., Mesri, G., (1996). *Soil mechanics in engineering practice.*.JohnWiley & Sonc Inc., Canada.

Titi H.H. *The increase in shaft capacity with time for friction piles driven into saturated clay.* PhD dissertation, Louisiana State University; 1996.

Tomlinson, M. J. (1970). *"Adhesion of piles in stiff clays."* Construction Industry Research and Information Association (CIRIA) Research Rep. No. 26, CIRIA, London.

Tomlinson, M. J. (2001). *Foundation design and construction.* Pearson education.

Welker, A. L., Bowders, J. J., & Gilbert, R. B. (1999). Applied research using a transparent material with hydraulic properties similar to soil. *ASTM Geotechnical Testing Journal*, 22(3), 266-270.

White, D. J., & Bolton, M. D. (2004). Displacement and strain paths during plane-strain model pile installation in sand. *Géotechnique*, 54(6), 375-397.

White, D. J., Take, W. A., & Bolton, M. D. (2003). Soil deformation measurement using particle image velocimetry (PIV) and photogrammetry. *Geotechnique*, 53(7), 619-631.

Woods, R. D. (1997). *Dynamic effects of pile installations on adjacent structures* (Vol. 253). Transportation Research Board.